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A SIMPLE LABORATORY METHOD FOR REDUCTION OF RHYTHM AND RATE IN LARGE-SCALE MONITORING OF ELECTROCARDIOGRAM

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by

James Roman
Flight Research Center

Fred M. Larmie
Northrop Corporation

and

Tulio R. Figarola
Lovelace Foundation

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SUMMARY

A laboratory system for rapid reduction of large amounts of continuously recorded ECG information has been developed. The system consists of a 60-times-real-time playback device which generates one pulse for each cardiac cycle, appropriate signal conditioning and logic circuitry, and a counting and printing system. Practical means for culling out noisy information, at 60 times real time, are provided.

In addition, modifications to the commercially available parts of the system have been made that significantly increase the reliability of diagnosis of ectopic events by the average investigator.

INTRODUCTION

The Avionics Research Products Corporation manufactures a device based on a development by Holter (ref. 1) which permits the screening of ECG information at 60 times real time. Rhythm changes can be noted, and instantaneous rate (beat by beat) is depicted on a cathode-ray screen. Although this equipment represents a significant and useful advance over what was previously available, it suffers from some deficiencies which made it marginally compatible for certain ongoing programs at the NASA Flight Research Center, Edwards, Calif. (ref. 2). Specifically, it was desired to document arrhythmias and ectopic beats completely and reliably in ECG information collected on magnetic tape (fig. 1) at the rate of up to 16 hours per day. Further, a printed or punched record of heart rate, preferably on a minute-to-minute basis, had to be available.

The main problem in reliably identifying rhythm changes or ectopic beats is that even the most skilled investigator cannot reliably, and with certainty, diagnose the

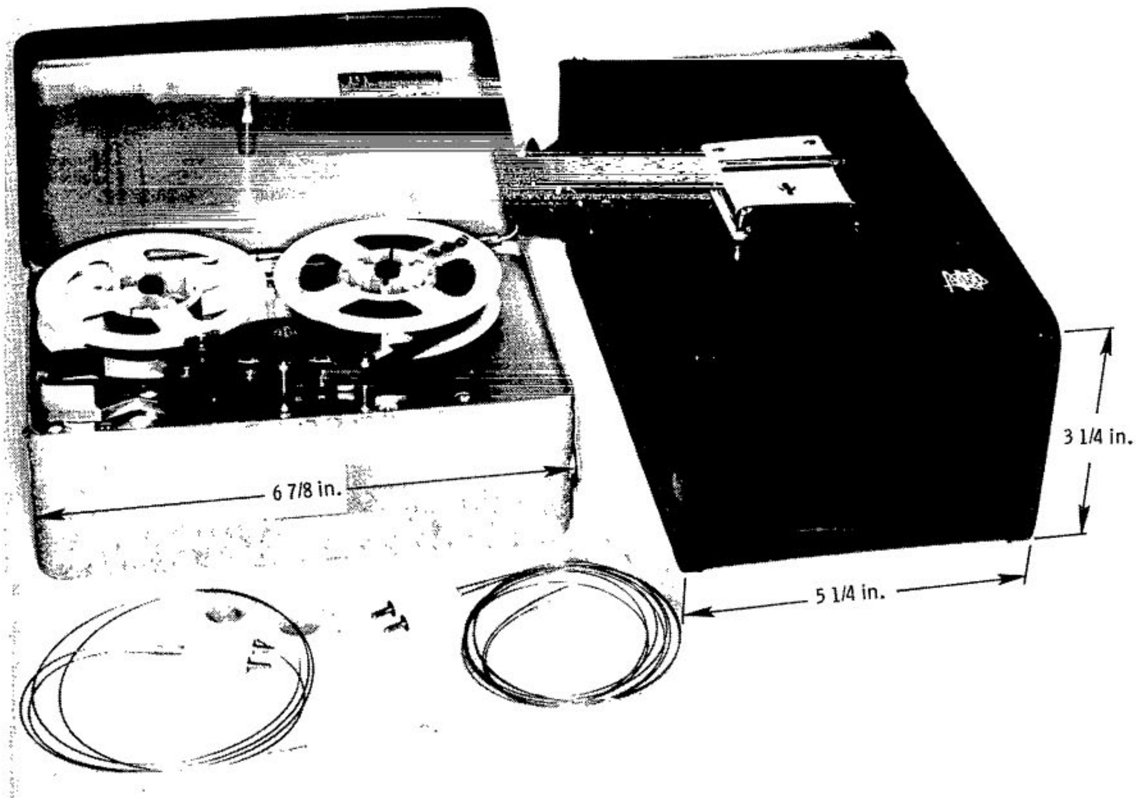

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Figure 1.– The Avionics recorder.

nature of each ectopic beat at 60 times real time. Although the cathode-ray screen might give a clear indication that an ectopic beat has occurred, the precise diagnosis must be made at less than 60 times real time. For that purpose, the Avionics Research Products Corporation has provided the electrocardiocharter, a device which plays back the magnetic tape at real time and allows a record of the electrocardiogram to be obtained. However, the process of switching the tape from an electrocardioscanner (60 times real time) to the electrocardiocharter (real time) is time consuming and requires manual dexterity. This problem and others made the complete diagnosis of rhythm changes in a continuous tape spanning several hours of recording, in the presence of noise, prohibitively time consuming for Flight Research Center purposes.

Although instantaneous rate information (beat by beat) is indicated on a cathode-ray screen in the electrocardioscanner, this is not useful for statistical analysis. The Flight Research Center needed a method that allowed printout of minute heart rate at 60 times real time or printout of the number of cardiac cycles in any desired period of time.

This paper describes the basic equipment (commonly known as the Audio Visual Superimposed Electrocardiogram Presentation (AVSEP)) as available commercially, the modifications and additions to the equipment made under contract and at the Flight Research Center, and the operating experience with the revised equipment at the Flight Research Center.

THE BASIC EQUIPMENT

Principle of Operation of the AVSEP System

The basic mode of the AVSEP system, as conceived by Holter (ref. 1), involves recording, on separate heads, two simultaneous tracks of identical ECG signal on magnetic tape, with the separate heads staggered to provide spatial separation of the signal along the long axis of the tape. On playback, one track is used as the signal track and, when played back at 60 times real time, modulates the vertical position of the electron beam on a cathode-ray screen. The other track is used as a trigger track in such a manner that each QRS complex starts a horizontal sweep of the electron beam. Since the trigger track is played back earlier in time than the signal track, because the heads are staggered, each QRS complex is precisely superimposed on the previous QRS complex on the cathode-ray screen at 60 times real time. This process results in a single, unchanging, stationary ECG waveform on the cathode-ray screen (fig. 2). When the waveform changes gradually, in real time, the change is smooth and gradual on the screen, much as it would be in a moving picture. Single ectopic beats appear as brief flashes on the cathode-ray screen of a different outline from the normal complex, although, because of the persistence of the cathode-ray screen, both complexes are actually seen simultaneously.

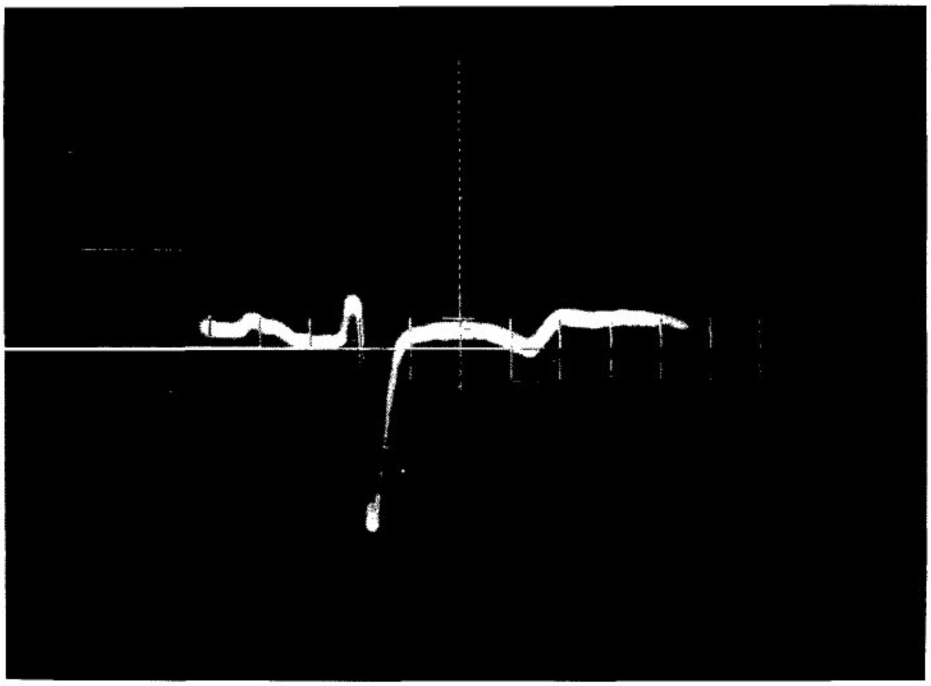

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Figure 2.– ECG waveform displayed on the electrocardioscanner.

The Recorder

In addition to the AVSEP principle, a significant and useful advance in the state of the art of the Holter system is the Avionics recorder (fig. 1). This device features recording times up to 10 hours, is portable (approximately 4 pounds), relatively inexpensive, and, with reasonable preventive maintenance, eminently reliable. It represents an essential part of the system, for no alternative for this device in terms of size, reliability, and price was available during 1966.

An electrocardiogram is recorded, using the electrocardiocorder in combination with any desired electrode system. Experience at the Flight Research Center has established that dry-spray electrodes (ref. 3) are significantly superior to many other types in recording continuously with the electrocardiocorder in studies that generally involved ground-based personnel. This superiority is partly because the spray electrodes permit the use of a sternal lead without the need for shaving. When it is desired to avoid shaving, in conjunction with conventional electrode techniques, such electrodes cannot generally be applied to the sternum. The sternal lead is by far the best compromise for the dynamic environment when it is desired to minimize the percentage of noise-degraded information. In situations in which the sternal lead is inadequate, such as when it is desired to attribute diagnostic meaning to S-T segment changes, it was found that the dry-spray electrodes tend to give acceptable recordings for much longer periods than do electrodes which have been applied with tape.

The Electrocardioscanner

Once the ECG record has been obtained, it is viewed at 60 times real time by using the electrocardioscanner (fig. 3). Threading the tape on the scanner is more involved

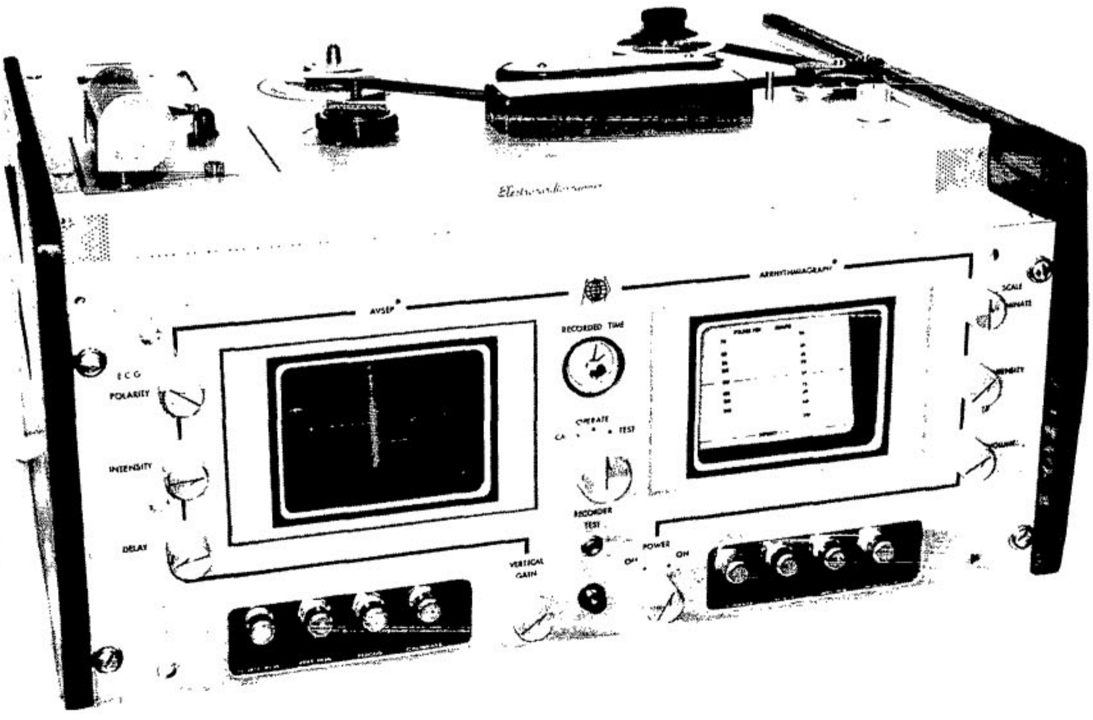

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Figure 3.–The electrocardioscanner.

and time consuming than the corresponding operation with the average commercial voice recorder. Incorrect threading can ruin large segments of recording. When screening for gradual waveform changes which persist, in real time, for periods of 30 seconds or more, use of the scanner is entirely satisfactory, without modification, in the hands of a practiced observer. Waveform changes that occupy a period of 30 seconds or more in real time persist on the screen sufficiently long (more than 1/2 second) at 60 times real time to be reliably differentiated from noise. On the other hand, the total cycle length of a single ectopic beat at 60 times real time is generally less than 1/100 of a second. In a very clean tracing, partly because of the persistence of the cathode-ray screen, a single ectopic beat can be differentiated from a short burst of noise or rapid baseline shift. However, the ectopic beat must be seen at some speed considerably below 60 times real time in order to be precisely classified with certainty. When the recording is associated with a significant amount of noise, not only is the precise diagnosis of an ectopic event usually not possible at 60 times real time, but many ectopic events cannot be differentiated from noise with a satisfactory degree of certainty.

The Electrocardiocharter

In a noisy tracing, the requirement arises frequently to look at portions of the recording at a speed slower than 60 times real time. In order to view segments of the tracing in real time, the electrocardiocharter is used (fig. 4). This procedure involves, first, the identification of the tape segment of interest. Precise means of doing this are not available, since a certain amount of backlash is unavoidably associated with the operation of the tape-driven mechanical clock used in this device.

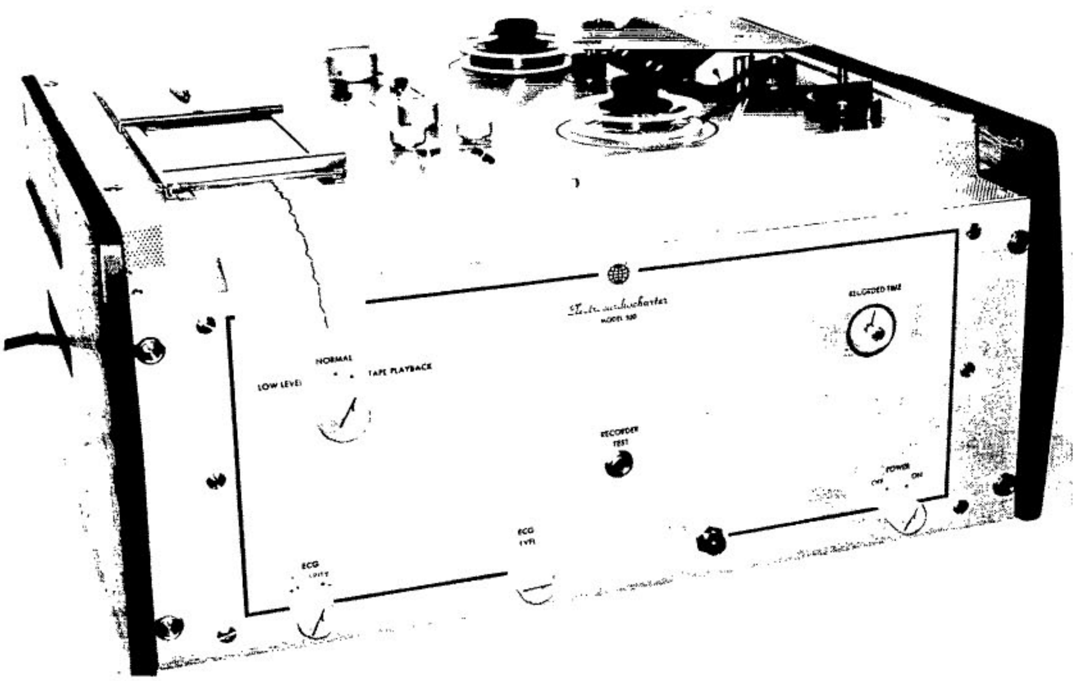

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Figure 4.– The electrocardiocharter.

Once the approximate location of the segment of interest has been determined, the tape is removed from the scanner and threaded onto the electrocardiocharter. The comments made previously about threading the electrocardioscanner also apply to threading the charter. Tape speed of the charter is 1/8 inch per second. A 7 1/2-inch error in lining up the tape in the charter will therefore be reflected in a 1-minute misalinement in terms of time. Because of all the factors involved, checking a single suspected ectopic event by moving the tape from the scanner to the charter, examining the portion of interest at real time, and returning the tape to the scanner takes the average operator several minutes. Yet, to study the incidence of certain ectopic events in a certain population, each suspected ectopic event must be individually checked. On tracings recorded on active subjects, and therefore having a certain amount of noise, this process can be quite time consuming.

THE NASA FLIGHT RESEARCH CENTER SYSTEM

Overall Features of the System

In order to closely adapt the Avionics system to the requirements of work in progress at the Flight Research Center, the following two steps were taken:

1. A contract was negotiated with Avionics Research Products Corporation for the design and development, to NASA specifications, of a new system that would permit the switch from 60 times real time to real time without changing the tape from one device to another.

2. The design and development was undertaken, at the Flight Research Center, of a system that would permit a digital count of minute heart rates (printed or punched) to be obtained at 60 times real time from Avionics tapes being played back on this new composite system.

The following characteristics are embodied in the new composite scanner as a result of requirements generated at the Flight Research Center:

1. Both 60 times real time and real-time playback heads, electronics, and drives are combined in one device. The tape passes the heads consecutively, although only one head is used at any one time. The change from 60 times real time to real time is accomplished by actuating two switches and does not involve rethreading the tape.

2. A variable low-pass filter was incorporated in the combined device to shape the trigger. This allows greater discrimination against noise to be obtained on problem tapes.

3. A variable band-pass filter is provided to condition the signal when played back at 60 times real time. This can be used to essentially eliminate 60-cycle noise, a large portion of any myogram, and considerable baseline shift on problem tapes.

4. Provisions are made to lock out the continuously variable vertical-gain feature and to use, instead, fixed settings of 1/2 millivolt per centimeter, 1 millivolt per centimeter, and 2 millivolts per centimeter.

It had been planned to prerecord time code on the edge of the magnetic tape in the new system in order to provide for improved time resolution in playback and to facilitate the identification of segments of interest. Incorporation of this feature proved to be too expensive to be considered.

It had also been planned to incorporate an intermediate scanning and playback speed either at 15 times real time or at 30 times real time. This feature, also, was too expensive to be justified.

In developing a system that would provide a permanent record of minute-by-minute heart rates, obtained at 60 times real time, the first step was to plot the arrhythmiagraph output versus time on an optical recorder at 60 times real time. In this fashion, an output of parallel vertical lines was obtained, the height of each vertical line being proportional to the period between consecutive heart beats (fig. 5). If the speed of the paper in the optical recorder was made sufficiently slow, it was easy to trace the envelope connecting the top of each of the vertical lines. This envelope was an approximation to an (inverse) instantaneous heart rate versus time curve; however, its usefulness was marginal as an indication of minute heart rate. The determination of mean or average levels of this curve for long periods, such as one minute, was fraught with difficulties and the resulting level, as estimated, was usually significantly

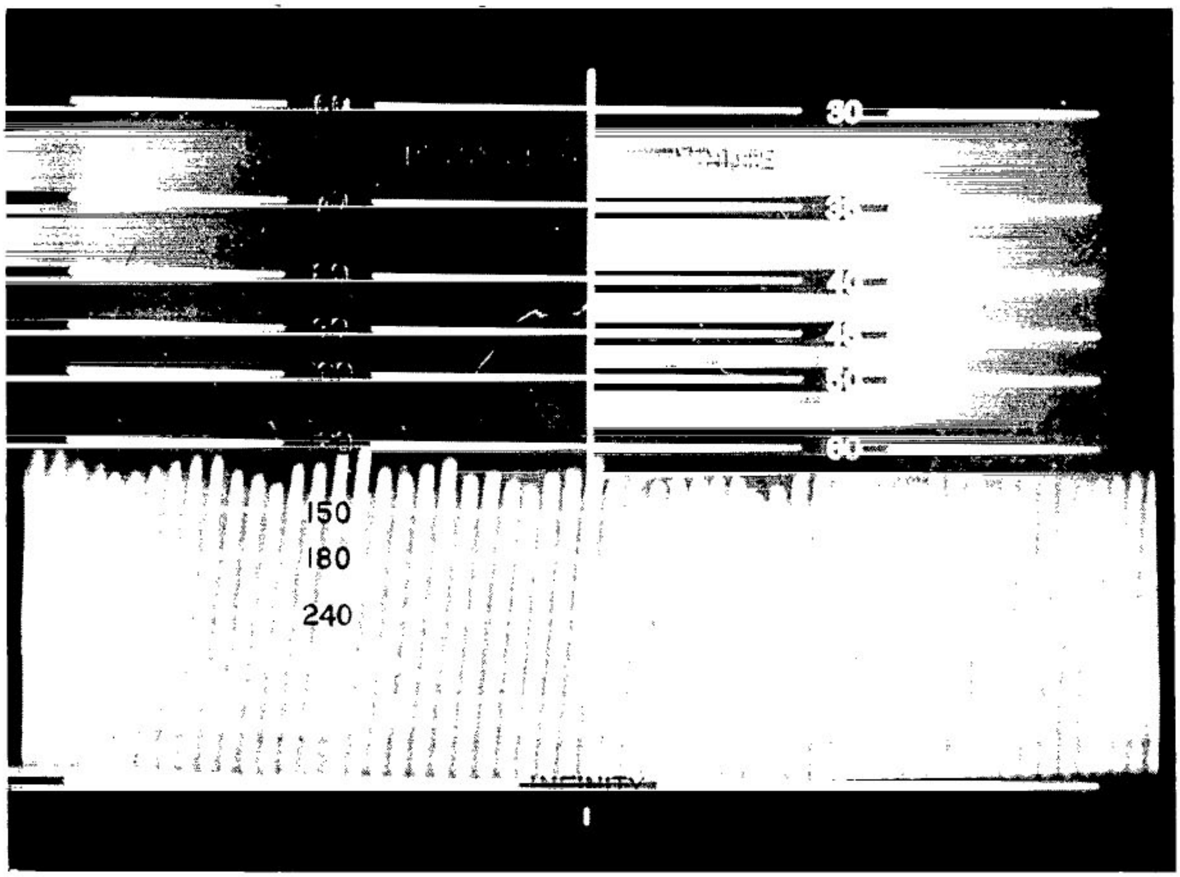


Figure 5.– Arrhythmiagraph displayed on the electrocardioscanner.

different from the actual count of cardiac cycles for the period under consideration. For Flight Research Center purposes, it was found to be more accurate and simpler to actually count the number of cardiac cycles for consecutive minute periods, or for any other time segment.

In the Flight Research Center system, cardiac cycles were counted essentially by feeding the trigger output of the scanner through appropriate delay and pulse shaping circuitry and logic into a digital counter. The counter was gated, as required, and the output of the counter was used as the input to a digital printer, although it could also be used as the input to a paper tape punch. Because the scanner operates at 60 times real time, the printer will print, once a second, the number of heart beats for a real-time period of 1 minute. Thus, consecutive numbers written by the printer once a second represent consecutive minute heart rates.

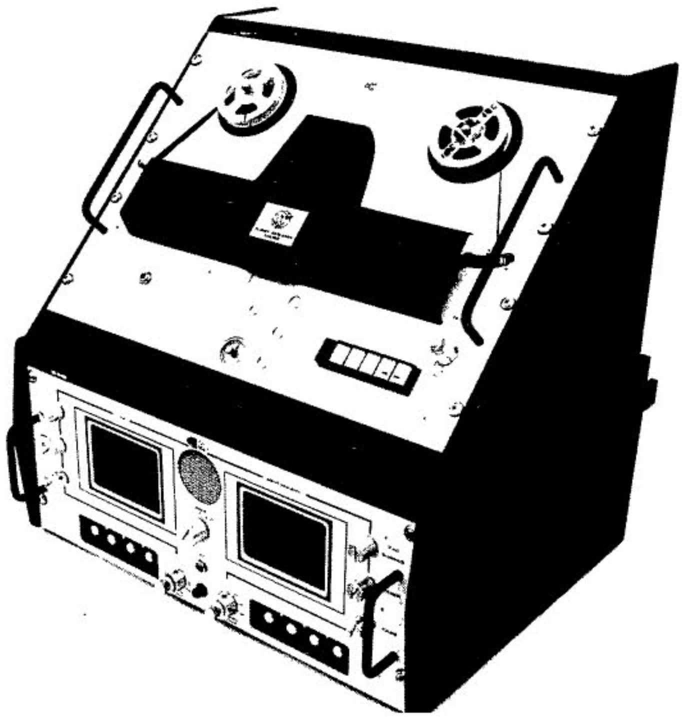
In a system of this type, a low signal-to-noise ratio will cause a printer to read out events other than cardiac cycles, i.e., noise. Consequently, at the Flight Research Center, the scanner screen is observed by an operator who short-circuits the input to the counter whenever a significant amount of noise is noted on the cathode-ray screen and causes a special identification mark to precede each doubtful minute heart rate on the printer output. Since it takes a finite amount of time for the operator to depress the appropriate switch whenever he observes a noisy signal, a tape loop was interposed between the trigger output and the filter in order to give the operator a fraction of a second of additional time before he needs to actuate the switch. This refinement is expensive and might not be considered necessary in many circumstances.

Two basic modes of determining heart rate are available with the Flight Research Center system, the one-minute counting mode and the full-tape counting mode.

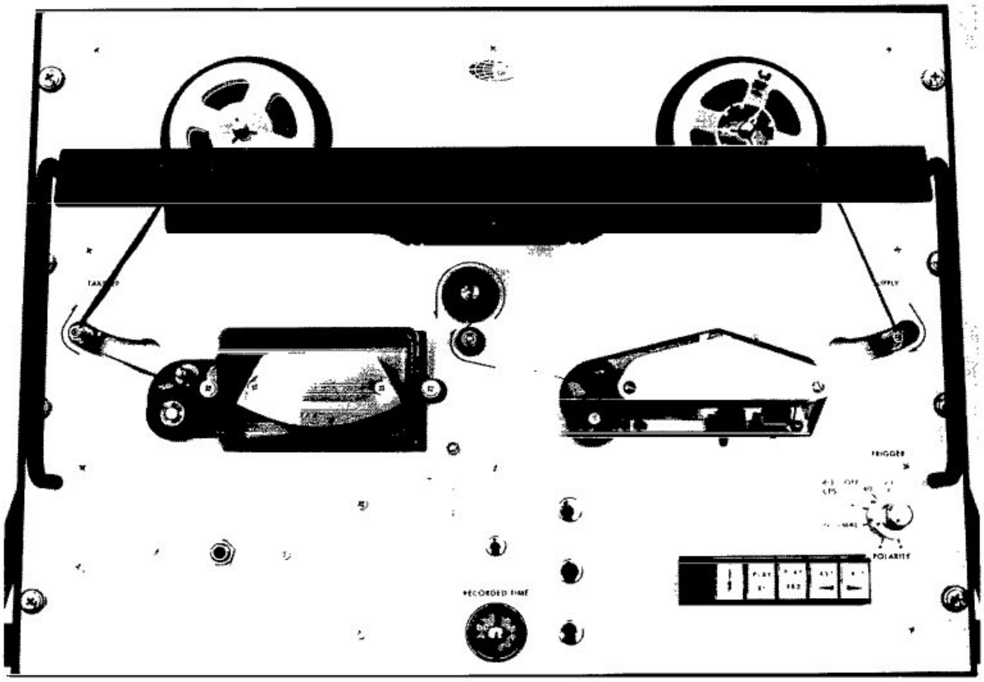
In the one-minute counting mode the pulses in the trigger output are counted for subsequent 1-second periods. Each sum is then printed out every second. Since the system operates at 60 times real time, every number printed represents a count of cardiac cycles for a 1-minute period, real time. When the counter recycles, a few pulses between adjacent samples are not counted. A comparison of averages, however, between this mode and the full-tape counting mode reveals a difference of less than 1.4 percent over a full 10-hour period.

In the full-tape counting mode the counter is not gated and continues to accumulate pulses until stopped by the operator. This mode is used when it is desired to obtain an average heart rate over a period other than 1 minute, for example, 10 hours. A timer free-runs as long as the counter is counting. Thus, the average heart rate for any period of time is obtained by dividing the reading shown on the counter (number of cardiac cycles) by the number of minutes shown on the timer. When the signal-to-noise ratio is low and the operator actuates the appropriate switch, the counter momentarily ceases to accumulate and, during that same period, the timer is momentarily stopped.

The combined cardioscanner developed under this program is shown in figure 6(a). Top and front panel views are presented in figures 6(b) and 6(c) in order to show the scanner and charter operating controls separately.

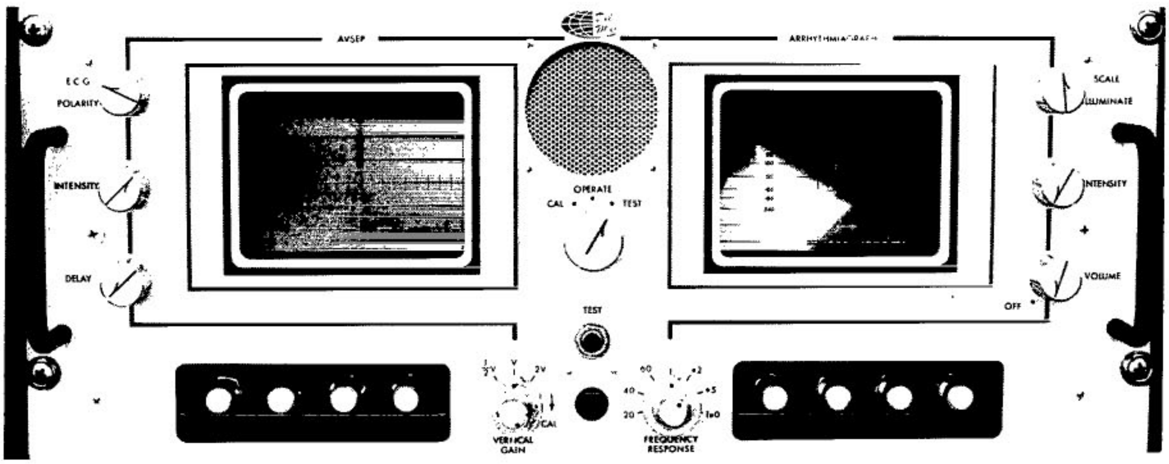


(a) Overall view. E-16979



(b) Top panel. A space is provided on the lower left for a direct writeout device. Note variable trigger filter at lower right. E-16977

Figure 6.– The combined scanner.



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(c) Front panel. Note fixed vertical-gain settings and variable band-pass filter for the signal.

Figure 6.– Concluded.

Circuitry

The circuitry required for the modifications discussed is detailed in the following paragraphs. This circuitry should pose no construction problems for the average university or hospital electronics section.

<u>High-speed digital system for counting and printing heart rate</u>.– The electrocardioscanner printout system was designed to provide 1-minute heart-rate counts on a digital recorder, or the total number of cardiac cycles in any desired time period, at 60 times real time. As shown in the block diagrams of figure 7, trigger pulses from the scanner are delayed through a closed-loop recorder, which enables the operator to mark the paper tapes or disable the counter on a noisy section of tape. The output pulses are then conditioned through a low-pass filter where they are shaped and amplified, thus providing more positive triggering of the digital counter. When

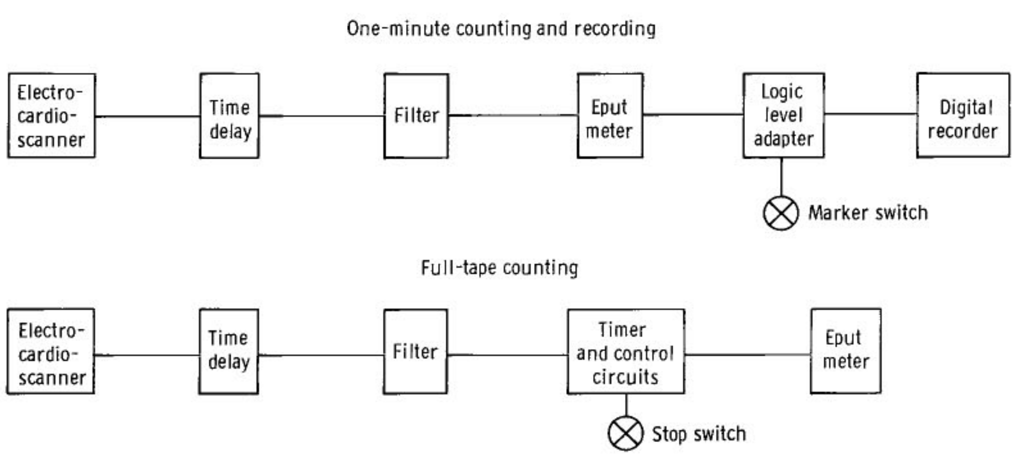

Figure 7.– High-speed digital system for totaling recorded electrocardiograms.

operated in the 1-minute counting mode, the logic level adapter is used to establish compatibility between the digital counter and the digital printer. On full-tape averaging, the total pulses are counted while time (seconds) is simultaneously counted by means of a timer. Both counts are interrupted by the operator when noise on the magnetic tape is detected.

Low-pass filter. – The low-pass filter (fig. 8) used to amplify and shape the electrocardioscanner output pulses has a bandpass of 300 hertz and a voltage gain of 23.5 decibels.

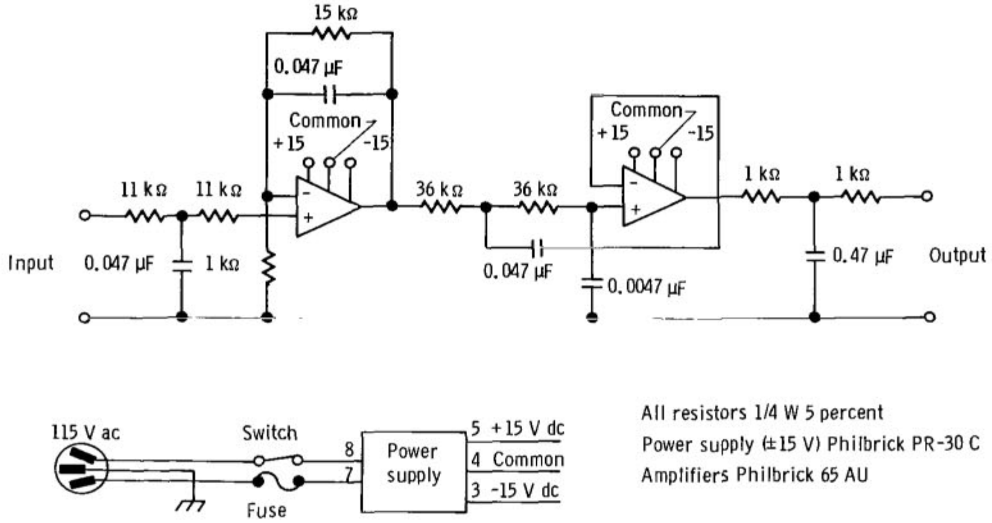

Figure 8.– Low-pass filter, 300 hertz.

Power supply. – The schematic diagram of figure 9 shows the inexpensive power supply used to energize the logic level adapter and various relays while providing isolation between the two systems.

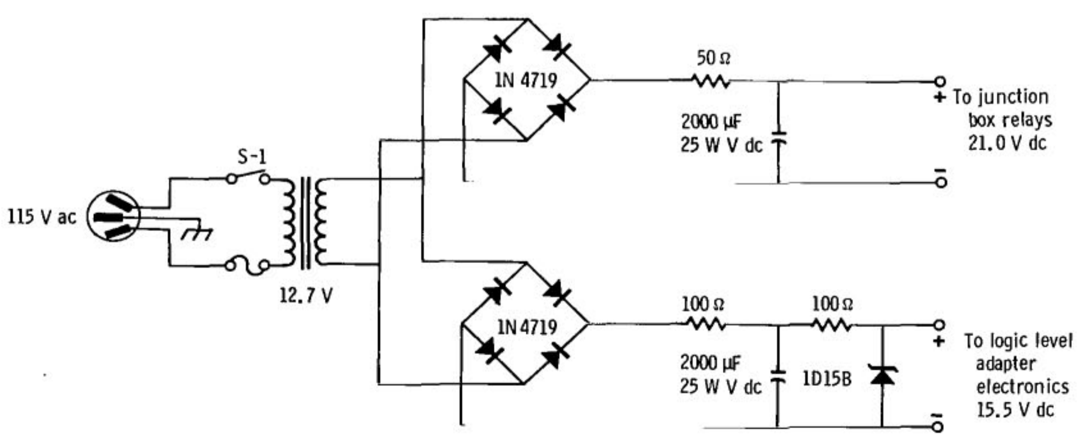

Figure 9.– Power supply.

System control circuitry. – The diagram of figure 10 shows the control circuitry for the electrocardioscanner counting system. When used in the 1-minute counting mode, activation of hand switch SW2 by the operator energizes relay K2, which closes the "noise reference marker" contacts. This results in placing a digit on the digital recorder tape in an unused channel. In the full-tape counting mode, activation of SW2 interrupts the trigger signal path at relay K1 contacts, and relay K2 contacts stop the timer.

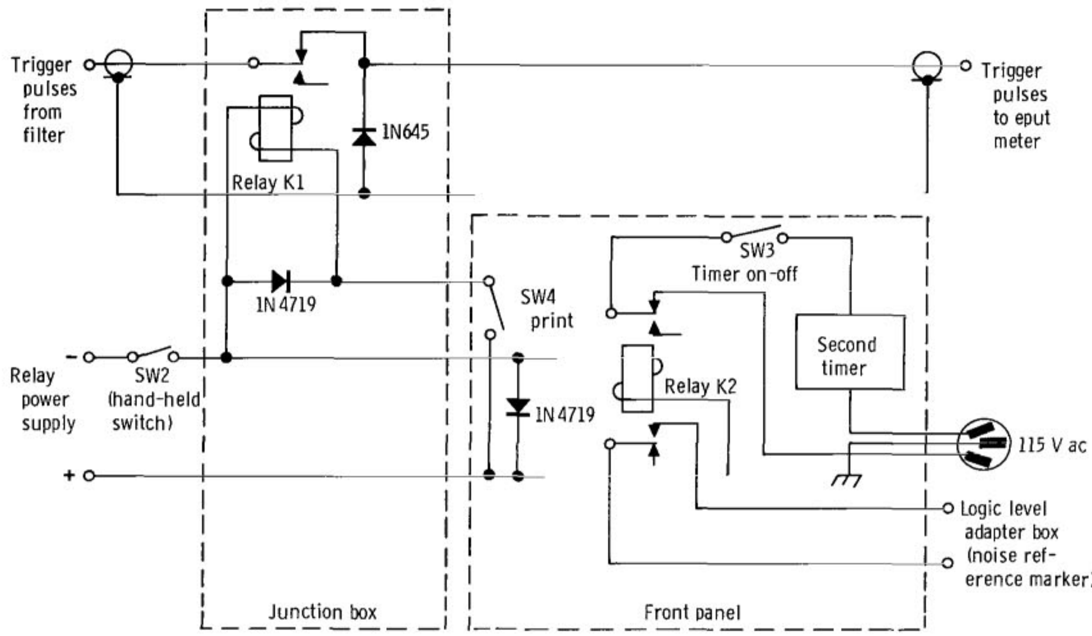

Figure 10.– System control circuitry.

Logic level adapter. – As shown in figure 11, the electrical output of the digital counter consists of four-line 1-2-4-8 binary-coded decimal information, which is compatible with the digital printer except for logic levels. This is remedied in the logic level adapter by shifting ground references between the two units and introducing a dc bias into the printer logic inputs. Large resistive dividers are used to provide minimal loading of the counter output and to couple the bias into the printer. A signal from the gate control binary stage in the digital counter is transferred into the printer through a transistor switch. This transfer occurs each time the counter gate closes and initiates printer operation with subsequent writeout. A front panel switch immobilizes printer operation. A digit printed on the paper tape is used as the noise reference marker and is initiated by applying a positive potential to one input stage through relay K2 contacts.

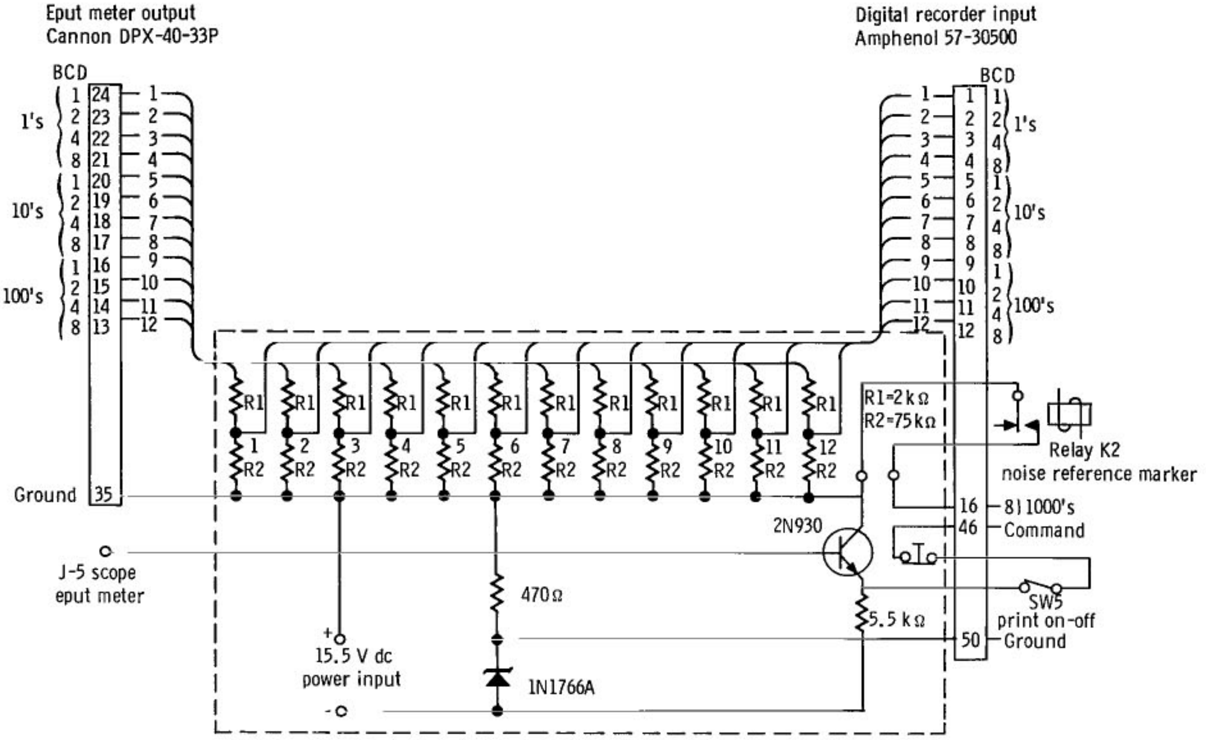

Figure 11.– Logic level adapter.

OPERATING EXPERIENCE

Over 1000 hours of continuous ECG information, most of which was obtained over a 3-month period, have been reduced for arrhythmias, ectopic events, minute rates, and overall rates, using the system described in this paper. In addition, the rate-counting feature of the system made possible a sophisticated statistical analysis of the factors that determine heart rate in a population of healthy adults during work and during sleep. This statistical study would not have been possible without the use of the system described herein.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., May 31, 1968,
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